REDUCTION OF DIESEL EXHAUST EMISSION BY USING FIRST STAGE SEA WATER SPRAY SYSTEM

MOHD AZMI BIN SITAM

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Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Air pollution from the diesel exhaust emission gives a bad effect to health and environment around the world. The content of the emission mostly harmful gases such as Nitrogen Oxide (NOx), Carbon Monoxide (CO), Hydrocarbon (HC) and Particulate Matter (PM). This thesis is aim to reduce diesel exhaust emission by using first stage seawater spray system. A spray chamber designed to setup together with the diesel engine for diesel experiment. The chamber is connected to the exhaust manifold to collect emission gas by using particle trap. Then, the emission data without seawater (WOS), with seawater (WS), and with electrolyzed seawater (WES) spray system for five variable engine speeds is analyzed using exhaust gas analyzer. The temperature change is also measured. The result had shown the comparison of emission concentration for three condition seawater sprays system in form of graph of emission concentration versus engine speeds. Most of the emission is reduce after flow through the spray chamber except for the oxygen that is increasing because of the additional oxygen in the seawater. The other emission is absorb by the alkaline seawater and dissolved in the seawater. The research had shown the effectiveness of alkaline seawater as a medium to reduce diesel exhaust emission. The emission WES spray is reducing more compares WS spray system. Furthermore, this research would also plan to add crank angle sensor on the engine to measure engine performance and study on content of waste seawater of this system.

ABSTRAK

Pencemaran udara dari pelepasan ekzos diesel memberi kesan buruk kepada kesihatan dan alam sekitar di seluruh dunia. Kandungan pelepasan kebanyakannya gas berbahaya seperti Nitrogen Oksida (NOx), Karbon Monoksida (CO), Hidrokarbon (HC) and Partikulat Terampai (PM). Tesis ini adalah bertujuan untuk mengurangkan pelepasan ekzos diesel dengan menggunakan sistem semburan air laut peringkat satu. Sebuah kebuk semburan direka bentuk untuk persediaan bersama-sama dengan enjin diesel bagi eksperimen diesel. Ruang itu disambungkan kepada pancarongga ekzos untuk mengumpul gas pelepasan dengan menggunakan perangkap zarah. Kemudian, data pelepasan mengunakan sistem semburan tanpa air laut (WOS), dengan air laut (WS), dan dengan terelektrolisis air laut (WES) untuk lima kelajuan enjin dianalisis menggunakan penganalisa gas ekzos. Perubahan suhu juga diukur. Keputusan menunujukkan perbandingan kepekatan pelepasan untuk tiga keadaan sistem semburan air laut dalam bentuk graf kepekatan pelepasan melawan kelajuan enjin. Kebanyakan pelepasan berkurangan selepas melalui ruang semburan kecuali oksigen yang semakin meningkat kerana oksigen tambahan di dalam air laut. Pelepasan lain juga diserap oleh air laut beralkali dan dilarutkan di dalam air laut. Penyelidikan menunjukkan keberkesanan air laut beralkali sebagai medium untuk mengurangkan pelepasan gas ekzos diesel. Pelepasan menggunakan semburan WES mengurangkan lebih banyak berbanding sistem semburan WS. Selain itu, kajian ini juga merancang untuk menambah sensor sudut engkol enjin untuk mengukur prestasi enjin.

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LIST OF SYMBOL

%	Percent
≤	Less than or equal
µ	Micro
^{0}C	Degree Celsius
d_D	Diameter of water droplets
e^-	Electron
H^+	Hydrogen’s Ion
K	Kelvin
kg	Kilogram
kWh	Kilowatt hour
m	Meter
nm	Nanometer
N_t	Impaction number
ø	Equivalence ratio
X_s	Stop distance

LIST OF ABBREVIATIONS

ATDC	After Top Dead Center
$Ba(NO_3)_2$	Barium Nitrate
$BaCO_3$	Barium Carbonate
BDC	Bottom Dead Center
Ca^{2+}	Calsium's ion
CFPP	Cold Filter Plugging Point
CI	Compression Ignition
Cl^-	Chlorine's ion
Cl_2	Chlorine gas
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
H^+	Hydrogen's ion
H_2S	Hydrogen Sulfide
HC	Hydrocarbon
HFRR	High-Frequency Reciprocating Rig
JSME	Japan Society of Mechanical Engineering
K^+	Potassium's ion
L/sec	Litter per second
LNC	Lean Nox Catalyst
MECA	Manufacturers of Emission Controls Association

Mg^{2+}	Magnesium's ion
N_2	Nitrogen gas
Na^{+}	Sodium's ion
NaOH	Natrium Hydroxide
NO	Nitric Oxide
NO_2	Oxide of Nitrogen
NOx	Nitrogen Oxide
O_2	Oxygen
OH^{-}	Hydroxide's ion
PMs	Particulate Matter
ppm	Part per million
rpm	Revolution per minute
SAE	Society of Automotive Engineers
SCR	Selective Catalyst Reduction
SI	Spark Ignition
SO_2	Sulfur Dioxide
SO_4^{2-}	Sulfate ions
SOF	Soluble Organic Fraction
SOx	Oxide of Sulfur
TDC	Top Dead Center
USA	United State of America
WES	With Electrolyzed Seawater
WOS	Without Seawater
WOT	Wide Open Throttle
WS	With Seawater

WSD	Wear Scar Diameter

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Diesel emission contained dangerous gases such as Nitrogen Oxide (NOx), Carbon Monoxide (CO), Hydrocarbon (HC) and Particulate Matter (PM). These gases give bad effect to human health and environment, for example respiratory irritant, ozone-forming and others. There are three area can be improved to control or reduce the emission for a better life in future. One of the areas is out of engine cleaning technologies or after treatment technology that use some form of scrubber or reactor to remove contaminants from the exhaust stream. These technologies can remove most of the contaminants from the exhaust gases, but maybe heavy, bulky and expensive and hence are not used unless needed (Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu et al. 2011). One of these technologies is use Selective Catalyst Reduction (SCR) to control NOx. SCR system use ammonia or urea as the reductant compound because of diesel lean burn combustion. This reductant is also help by an auxiliary oxidation catalyst to modify NOx ratio.

In other hand, NOx adsorbers technology was originally developed for lean-burn, low-emission gasoline engines but is now being adapted for diesel engines. The adsorbers are incorporated into a catalyst wash coat and chemically bind NOx during normal lean (oxygen-rich) engine operation. After the adsorber capacity is saturated, the system is regenerated. The released NOx is catalytically reduced during a short period of rich engine operation, using a conventional 3-way catalytic converter (Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu et al. 2011). By using Exhaust Gas

Recirculation (EGR), NOx emissions can be reduced. EGR function is recirculate portion of the engine's exhaust back to the intake manifold.

In this project, the use of seawater spray system will introduce a new technology to reduce the diesel emission. Seawater has interesting possibility due to the strong acidity and alkaline seawater play an important role in NO oxidation and CO absorption respectively (Sukheon An & Osami NISHIDA, 2003). This system allows the exhaust gases thorough a mixer with seawater spray to remove SOx, CO_2, NOx, CO and PM.

1.2 PROBLEM STATEMENT

Today in this modern world, there are many application of diesel engine on the road or on the sea. Diesel engine usages give the advantages but also disadvantages in the same time due to diesel exhaust emission. The main problem is the negative effect of the emission toward the environment and human's health especially if there no emission control.

One of the ways to reduce the emission is by using seawater spray system. This system is considered new technology for exhaust emission after treatment. This system use seawater to make contact with exhaust gases using spraying method. The problem using this seawater is the effectiveness of seawater as a medium to reduce the emission. So, this project will analyze the emission characteristic comparison with or without reduction system.

1.3 PROJECT OBJECTIVE

There is one objective for this project which is to measure reduction of diesel exhaust emission such as CO, CO2, O2, and NOx by diesel experiment using seawater spray system. The analysis is to compare between system with and without seawater spray for diesel engine operation.

1.4 PROJECT SCOPE

This project is to analyze the emission characteristic before and after use seawater spray system during direct contact with seawater. This project also to design and construct sea water spray system, setup sea water spray into diesel experimental rig, experimental by diesel engine and then analysis of exhaust emission by the application of exhaust gas analyzer.

CHAPTER 2

LITERATURE REVIEW

2.1 EXHAUST GAS AFTERTREATMENT TECHNOLOGY

From Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu (2011), one of the three technologies to reduce diesel emission is out of engine technology. This technology also calls exhaust gas aftertreatment technology that used to reduce NOx and other harmful compound in exhaust. For this technology, it have several method can be used for control the dangerous gas produce by diesel engine combustion. Selective Catalyst Reduction (SCR) is one the effective method to control NOx. This method has been installed for the first marine SCR in 1989 and 1990. SCR system is use ammonia or urea as the reductant compound because of diesel lean burn combustion and wide used as a source of nitrogen in agricultural application. This reductant is also help by an auxiliary oxidation catalyst to modify NOx ratio. But effect of difficulty in handling ammonia, urea is used because it can decompose to ammonia by heating in 2 -3 meter hot exhaust pipe. This SCR is effective to reduce the NOx about 92%. While For medium- speed diesel engine application, 90 to 95% NOx reduction (EPA 2009) is possible under steady-state conditions where the exhaust gas temperature is above 270 °C. Another NOx reduction option is Exhaust Gas Recirculation (EGR). EGR help by recycled the exhaust gas back into the engine charge air (intake valve) and then reduce the peak combustion chamber temperature. From the laboratory research, the NOx reduction can reach 10% - 30% with marginal increasing the fuel consumption. Other than that, EGR also can achieve 40% reduction of NOx (MECA 2006). But for experiment of 4T50ME- X low speed engine with EGR system by MAN B&W, the NOx reductions can up to 70%. The same result has been report by EPA (2009) with combination of intake air humidification.

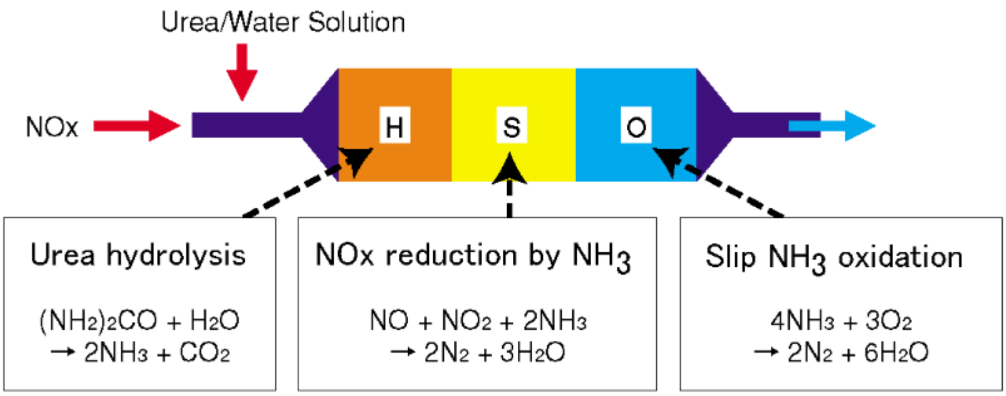

Figure 2.1: the Scheme of a Generic Selective Catalyst Reduction (SCR) System.

Source: Hideaki HAMADA, (2009)

NOx adsorbers are the newest control technology being developed for diesel NOx control. The technology was originally developed for lean-burn, low-emission gasoline engines but is now being adapted for use in diesel engines. The adsorbers are incorporated into a catalyst wash coat and chemically bind NOx during normal lean (oxygen-rich) engine operation. After the adsorber capacity is saturated, the system is regenerated. The released NOx is catalytically reduced during a short period of rich engine operation, using a conventional 3-way catalytic converter. The reaction steps for lean NOx conversion are shown schematically in Figures 2.2 and Figures 2.3. The NO is adsorbed and chemically binds with barium carbonate ($BaCO_3$) to form barium nitrate ($Ba(NO_3)_2$). During regeneration the diesel exhaust gas is rich in CO and unburned hydrocarbons. These chemicals reduce $Ba(NO_3)_2$ back to $BaCO_3$, in the process releasing NOx. In a downstream 3-way catalytic converter the NOx is reduced by the rich exhaust gases to Nitrogen (N_2).

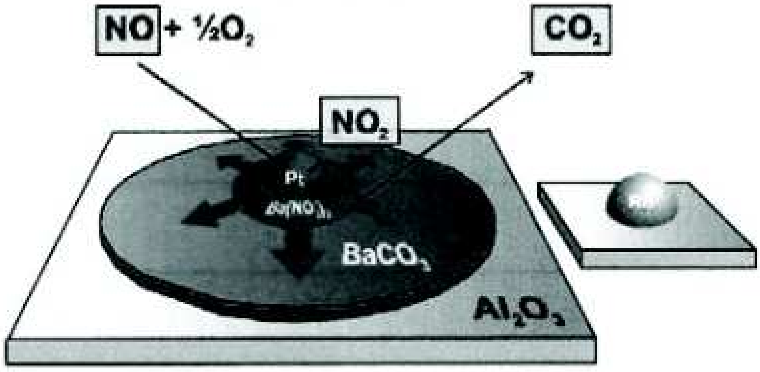

Figure 2.2: Lean Condition

Source: From Jingbo, Y. et al. (2011).

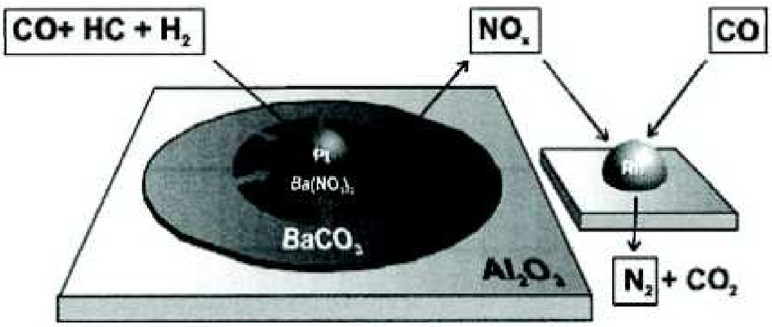

Figure 2.3: Rich Condition

Source: From Jingbo, Y. et al. (2011).

Lean NOx Catalyst (LNC) system help in control exhaust emission by inject a small amount of diesel fuel or other reductant into the exhaust upstream of the catalyst (MECA 2006). The fuel or other hydrocarbon reductant serves as a reducing agent for the catalytic conversion of NOx to N_2. Without the added fuel and catalyst, reduction reactions that convert NOx to N_2 would not take place because of excess oxygen present in the exhaust. As the result of this system, the efficiency of NOx conversion for the system is around 10% - 30%. A same method have reported by Cauda, E.G. et al.

(2010) explained that , in a few applications, unburned hydrocarbons from the engine chamber are sufficient to obtain the desired NOx conversion, otherwise a post-injection of hydrocarbon in the exhaust is necessary (Dorriah 1999). Besides that, the convection of NO and NO_2 depends mostly on the catalyst chemical formulation and configuration. This LNC system reported that can achieved maximum NOx convection until 60% for diesel engine operate over real duty cycle (Kharas et al. 1998). But it has the weakness of this system which high complexity of the chemical reactions employed by these systems and the requirement of a constant emissions monitoring and tuning, can delay the introduction of these technologies in mining equipment.

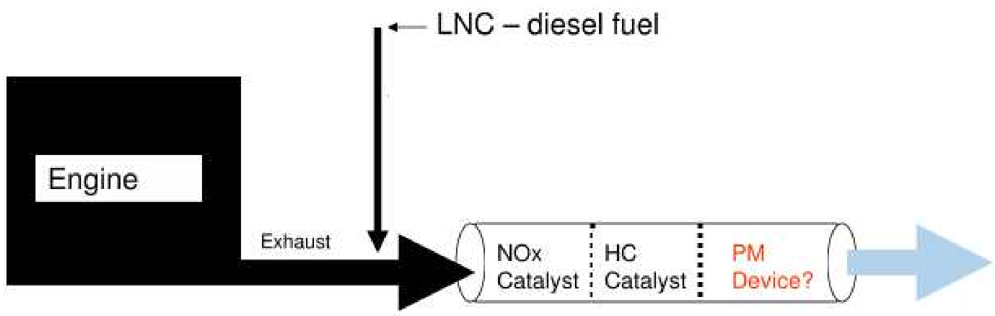

Figure 2.4: Scheme of LNC System.

Source: Hideaki Hamada, (2009).

2.2 SEAWATER SCRUBBER

From Sukheon AN and Osami NISHIDA (2003), explained about the usage of seawater and its electrolysis for the exhaust emission control in diesel engine. For a slow speed diesel engine operating on heavy fuel oil and at normal service load, the composition of the exhaust gases is contain higher NOx 1220 ppm, compare to other gases such as SO_2 660 ppm, HC 120 ppm and CO 50 ppm. So the method of wet scrubber system using seawater is performed to control exhaust emission. This system is used to spray the seawater to contact with exhaust gases. By spray naturally seawater at pH around 8.1, the SO_2 and SO_3 can be remove because high solubility with seawater.

The other exhaust pollutant such as Particular Matter (PMs) removed when through direct contact with the seawater droplets. Then, chemical reaction between oxygen and water was form sulfate ions (SO_4^{2-}) and hydrogen ions (H+) as shown Eq. (2.1).

$$SO_2 + H_2O + 1/\,2O_2 \longrightarrow SO_4^{2-} + 2H^+ \tag{2.1}$$

For the PM, the removal effect is proportional to the impaction number (N_t) between particles and water droplets where X_s is stop distance, d_D is diameter of water droplets as shown in Eq. (2.2).

$$N_t = X_s / d_D \tag{2.2}$$

In other hand, NOx and CO_2 can absorption by electrolysis seawater that contain with NaOH and other alkali metal ion. But for NOx's case, it must to oxidize NO to NO_2. They were introducing the seawater scrubber system and name it as Two- Stage Wet Scrubber System. For the first- stage, it used only seawater to remove SOx and PMs. The chemical reaction of SO_2 with seawater can form sulfate ions (SO_4^{2-}) and hydrogen's ion (H^+). They also expect the reduction of SOx is 93 -98 %, 85 -90% PMs, 20- 30% NOx and 5- 10% CO_2. In other case, SO_2 emission reduction of 66% has been found to require approximately 40 – 63 kg of seawater per kWh depending on the salinity and alkalinity of the seawater used in the scrubber. Report by Dr. Brigitte Behrends and Prof. Dr. Gerd Liebezeit (2003) said that 90 – 95% SO_2, 10 – 20% NOx, 80% particulate and 10 -20% hydrocarbon can remove by apply seawater scrubber system on ship while for plant it can remove SO_2 up to 99%.Continue with the second-stage which is seawater electrolysis is use to absorb the remaining NOx and CO_2 untreated in first –stage. In that treatment, it forms chemical reaction to form nitric acid (HNO_3) from NOx as shown in Eq. (2.3). Their experiment was conduct by link the exhaust gases from the combustor to the scrubber with the exhaust pipe. Then, in the scrubber the 3 nozzle spray the seawater to wash the gases before it discharge to atmosphere. During the exhaust gases through the scrubber, the data was obtained from two points at inlet and outlet of the scrubber. The data taken was exhaust gas temperature and pH value. Lastly, as their conclusion, the SOx removal could be achieved nearly perfect and same as PMs. The seawater electrolysis is suitable for absorption of NOx and CO_2.

$$2NO_X + H_2O + (2.5 - x)\ O2 = 2HNO_3 \tag{2.3}$$

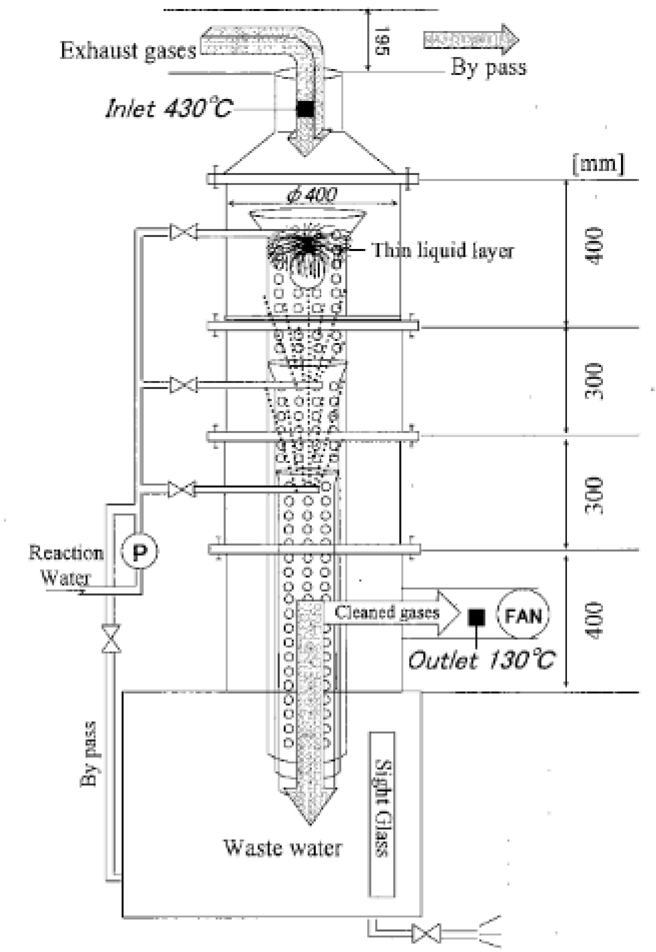

Figure 2.5: Seawater Scrubber System Diagram.

Source: An, S. and Nishida, O. (2011)

2.3 CHARACTERISTIC OF DIESEL ENGINE

2.3.1 Diesel Engine History

Martynn Randall (2004) stated that the first commercially – successfully compression – ignition engine was invented by Rudolf Diesel at the end of the 19^{th} century. Compared to spark ignition engine, diesel engine had the advantages of lower fuel consumption, the ability to used cheaper fuel, the potential to much higher power output. Over the following two or three decades, diesel engine were widely used for stationary and marine applications, but the fuel injection system used were not capable of high – speed operation. This speed limitation, and considered the considerable weight of the air compression needed to operated the injection equipment, made the first diesel engine unsuitable for use in road- going vehicle.

In the 1920s, the in – line injection pump was develop by German engineer Robert Bosch. The use of hydraulic system to pressurize and inject the fuel did away with the need for a separated air compressor, and made possible much higher operating speed. This engine was manufacture in two stroke and four stroke versions.

In the 1930s, they slowly began to be used in a few automobile. Until 1950s and 60s, diesel engine increasingly popular for use in taxis and vans, but it was not until the sharp rises in oil price in the 1970s. So, at the end 1977s the introduction of diesel – powered Golf come out with the first “user – friendly” diesel car. Then, the used of diesel engine in large on – road and off – road vehicle in the USA increased. As of 2007, about 50 percent of all new car sales in Europe are diesel.

2.3.2 Basic Principle of the Diesel Engine

Sean Bennett (2010) stated that the diesel cycle is by definition a four – stroke cycle. A cycle is a sequence of event. So, the diesel engine is best introduced by outlining of the four strokes of the pistons made as an engine in turned through two revolutions. A full cycle of diesel engine requires two complete rotations. Each rotation requires turning the engine through 360 degrees, so a complete diesel cycle translates into 720 crankshaft degrees. Then, each of the four strokes that make up the diesel cycle involve moving a piston either from top of its travel to its lowest point of travel or vice versa. For each, strokes of the cycle can translate into 180 crankshaft degrees. The four strokes for the four – stroke cycle are: 1) intake, 2) compression, 3) power, 4) exhaust.

4 – Stroke cycle

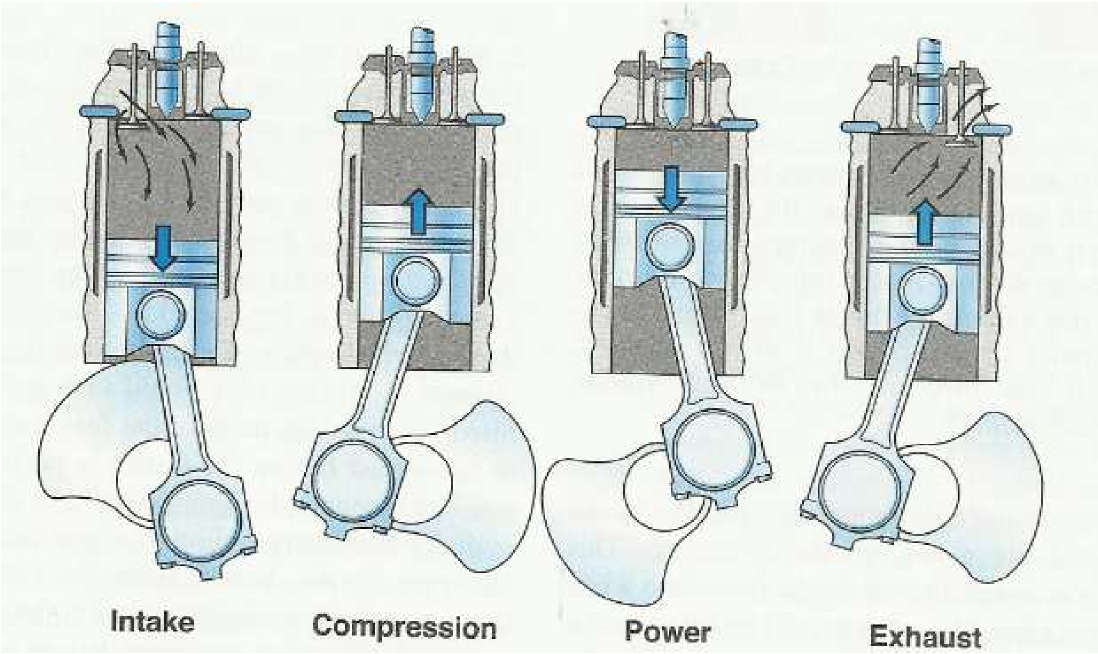

Figure 2.6: Four – Stroke Cycle Diagram

Source: Barry Hollembeak (2005)

Stroke 1 “intake”: The piston is connected to the crankshaft throw by means of a wrist pin and connecting rod. The thrown is an offset journal on the crankshaft. Therefore, as the crankshaft rotates the piston is drawn from top dead center (TDC) to bottom dead center (BDC). While the piston moves through its downstroke, the cylinder head intake valves are held open and air filled into the cylinder. The completion of intake stroke is when the intake valve closed and the cylinder will be filled with the air. The air is contain with one – fifth oxygen where is required to combust the fuel.

Stroke 2 “compression”: After completion of the intake stroke, the piston is now driven upward from BDC to TDC with the intake and exhaust valves closed. The quantity of air in the cylinder is still the same but compressing the air gives it much less space and heats it up considerably.

Stroke 3 “power”: Shortly before the completion of compression stroke, atomized fuel is introduced directly into the engine cylinder by multi – orifice nozzle assembly. The fuel exits from the nozzle at very high pressure and in liquid stage. Then, the liquid emitted by the injector must size appropriately for ignition and combustion. Once exposed to the heated air charge in the cylinder, the fuel droplets are first vaporized and the ignited. The ignited occur just before the piston is positioned at TDC. Effect of the power stroke, the piston driving it downward and call as expansion.

Stroke 4 “ exhaust” : Somewhere after 90 degrees after top dead center (ATDC) during the expansion, most of the heat energy that can be convert to kinetic energy has been converted and the exhaust valves open. The product of cylinder combustion is known as end gas or exhaust gas.

2.3.3 Diesel Fuel Characteristic

High-quality diesel fuels are characterized by the following features (Challen and Baranescu, 1999):

- High cetane number
- Relatively low final boiling point
- Narrow density and viscosity spread.
- Low aromatic compounds (particularly polyaromatic compounds) content
- Low sulfur content.

In addition, the following characteristic are particularly important for the service life and constant function of fuel-injection systems.